Kalamazoo Section
American Chemical Society (KACS)

COMPETITIVE SCHOLARSHIPS IN CHEMISTRY
FINAL EXAMINATION

APRIL 2024

Put your **first** and **last name** on both the question paper and scantron sheet in the spaces provided and blacken the spaces that correspond to your answer.

Please make sure you have 45 questions on the examination.

A periodic table and scantron sheet are included. No other charts and tables are permitted.

Ti-31 calculators may be used, but not shared.

1) The density of gas A is twice that of gas B. The molecular mass of A is half that of the molecular mass of B. The ratio of the partial pressure of A to B is ______?

a) 1:4
b) 1:2
c) 4:1
d) 2:1

2) Which of the following compounds will exhibit *cis-trans* isomerism?

a) Butanol
b) 2- Butyne
c) 2-Butenol
d) 2-Butene

3) Which one of the following complexes has the highest conductivity in an aqueous solution:

a) $[Co(NH_3)_3Cl_3]$
b) $[Co(NH_3)_4Cl_2]Cl$
c) $[Co(NH_3)_6]Cl_3$
d) $[Co(NH_3)_5Cl]Cl_2$

4) If a soap has a high alkali content, it can irritate the skin. How can the amount of excess alkali be determined?

a) Using a pH meter
b) Using chromatography
c) Acid-base titration
d) By filtration

5) Which one among the four bases is not present in DNA.

a) Adenine (A)
b) Guanine (G)
c) Cytosine (C)
d) Uracil (U)

6) When work is done on a system or by a system there is a change in _______.

a) external energy
b) internal energy
c) adiabatic energy
d) isothermal energy

7) What is the relationship between reaction quotient and Gibbs free energy at a given temperature, *T*?

a) $\Delta G = \Delta G^0 + RT\ lnQ$
b) $\Delta G = \Delta G^0 + RT\ lnk$
c) $\Delta G = \Delta G^0 + R\ lnQ$
d) $\Delta D = \Delta G^0 + RT\ lnQ$

8) Reduction involves a _______ in oxidation number.

a) decrease
b) increase
c) independence
d) remains constant

9) A vessel at equilibrium contains SO_3, SO_2 and O_2. Some helium gas is added so that total pressure increases while temperature and volume is held constant. According to Le Chatelier's Principle the partial pressure of SO_3 _______.

a) decreases
b) remains constant
c) increases
d) none of the above

10) Which of the following is the correct order for the stability of their +1 oxidation states?

a) Ga < In < Tl
b) Ga < In > Tl
c) Ga > In < Tl
d) Ga > In > Tl

11) Arrange the following in the increasing order of electronegativity.

a) $sp^2 < sp < sp^3$
b) $sp^3 < sp^2 < sp$
c) $sp < sp^2 < sp^3$
d) $sp^3 < sp < sp^2$

12) $SnCl_2 + 2FeCl_3 \rightarrow SnCl_4 + 2FeCl_2$ is an example of ________ reaction.

a) only oxidation
b) only reduction
c) redox
d) neither oxidation nor reduction

13) In which of the following cases does the reaction go farthest to completion based on the equilibrium constant, K?

a) K = 1
b) K = 10
c) $K = 10^{-2}$
d) $K = 10^{2}$

14) At 25°C and 730 Torr, 380 mL of dry oxygen is stored in a balloon. If the temperature is constant, what volume of oxygen will occupy at 760 Torr?

a) 365 mL
b) 449 mL
c) 569 mL
d) 621 mL

15) Which of the following is a chemical change?

a) Freezing of water to ice
b) Rusting of iron
c) Crumpling a sheet of aluminum foil
d) Casting silver

16) If the value of Gibbs free energy for a reaction is 20 J/mol, the reaction is ________.

a) spontaneous
b) non-spontaneous
c) may be spontaneous
d) may not be spontaneous

17) OMITTED

18) Alkali metals are strongly _________.

a) neutral
b) electropositive
c) electronegative
d) non-metallic

19) The correct order of the packing efficiency in different types of unit cells is ________.

a) fcc $<$ bcc $<$ simple cubic
b) fcc $>$ bcc $>$ simple cubic
c) fcc $<$ bcc $>$ simple cubic
d) bcc $<$ fcc = simple cubic

20) An antifreeze solution is prepared from 222.6 g of ethylene glycol $C_2H_4(OH)_2$ and 200 g of water. If the density of this solution is 1.072 g/mL, what will be the molarity of the solution?

a) 7.20 M
b) 12.03 M
c) 9.11 M
d) 6.00 M

21) In which of the following processes will the standard entropy change, $\Delta S°$, be negative?

a) $C_2H_5OH(l) \rightarrow C_2H_5OH(g)$
b) $NaCl(s) \rightarrow NaCl(l)$
c) $CO_2(s) \rightarrow CO_2(g)$
d) $Cl_2(g) \rightarrow Cl_2(l)$

22)

Solutions	0.1 M $HC_2H_3O_2(aq)$	0.1 M $KI(aq)$	0.1 M $CH_3OH(aq)$

Of the three solutions listed in the table above, which one, if any, has the greatest electrical conductivity and why?

a) 0.1 M $HC_2H_3O_2(aq)$ because its molecules have the most atoms.
b) 0.1 M $KI(aq)$ because KI completely dissociates in water to produce ions.
c) 0.1 M $CH_3OH(aq)$ because its molecules can form hydrogen bonds.
d) All three solutions have the same electrical conductivity because the concentrations are the same.

23)

Compound	Formula	Boiling Point (°C)	Density (g/mL)
Hexane	C_6H_{14}	69	0.66
Octane	C_8H_{18}	126	0.70

A student obtains a liquid mixture of hexane and octane, which are miscible in all proportions. Which of the following techniques would be best for separating the two compounds of the mixture, and why?

a) Filtration, because the different densities of the liquids would allow one to pass through the filter paper while the other would not.
b) Paper chromatography, because the liquids would move along the stationary phase at different rate owing to the difference in polarity of their molecules.
c) Column chromatography, because the higher molar mass of octane would cause it to move down the column faster than hexane.
d) Distillation, because the liquids would boil at different temperatures owing to the difference in strength of their intermolecular forces.

24) $$Ge(g) + 2\ Cl_2(g) \rightleftharpoons GeCl_4(g)$$

The value of the equilibrium constant, K, for the reaction represented above is 1×10^{10}. What is the value of the equilibrium constant for the following reaction?

$$2\ GeCl_4(g) \rightleftharpoons 2\ GeCl_4(g) + 4\ Cl_2(g)$$

a) 1×10^{-20}
b) 1×10^{-10}
c) 1×10^{10}
d) 1×10^{20}

25) To catalyze a biochemical reaction an enzyme typically

a) drives the reaction to completion by consuming byproducts of the reaction.
b) binds temporarily to reactant molecules to lower the activation energy of the reaction.
c) dissociates into additional reactant molecules, thereby increasing the reaction rate.
d) decomposes and releases energy to increase the number of successful collisions between reactant molecules.

26) $$CO_2(g) + 2\ LiOH(s) \rightarrow Li_2CO_3(aq) + H_2O(l)$$

An emergency diver fitted with a scuba rebreather exhales 36.67 g $CO_2(g)$ per hour. To prevent the buildup of $CO_2(g)$ in the recycled air, a device containing $LiOH(s)$ is used to remove the $CO_2(g)$, as represented in the equation above. What mass of $LiOH(s)$ is needed to react with all the $CO_2(g)$ produced by the diver in eight hours?

a) 13.33 g
b) 80 g
c) 160 g
d) 320 g

27)

Time (s)	$[NO_2]$ (mol/L)	ln $[NO_2]$	$1/[NO_2]$ (L/mol)
0	0.500	-0.693	2.00
100	0.364	-1.01	2.75
200	0.286	-1.25	3.50
300	0.235	-1.45	4.25

The data from a study of the decomposition of $NO_2(g)$ to $NO(g)$ and $O_2(g)$ are given in the table above. Which of the following rate laws is consistent with the data?

a) Rate = $k[NO_2]$
b) Rate = $k[NO_2]^2$
c) Rate = $k/[NO_2]$
d) Rate = $k/[NO_2]^2$

28) In an experiment, 30.0 g of ethane and 30.0 g of propanol are placed in separate reaction vessels. Each compound undergoes complete combustion with excess $O_2(g)$. Which of the following best compares the quantity of heat released in each combustion reaction?

a) $q_{\text{ethane}} < q_{\text{propanol}}$
b) $q_{\text{ethane}} = q_{\text{propanol}}$
c) $q_{\text{ethane}} > q_{\text{propanol}}$
d) The quantities of heat released in the combustions of ethane and propanol cannot be compared without knowing the specific heat capacity of the compounds.

29) A solution is prepared by mixing equal volumes of 0.20 M $HC_2H_3O_2$ and 0.40 M $NaC_2H_3O_2$. Which of the following correctly describes what occurs if a small amount of HCl(*aq*) or NaOH(*aq*) is added?

a) If HCl(*aq*) is added, the pH will increase only slightly because the Cl^- ions will react with $C_2H_3O_2^-$ ions.
b) If HCl(*aq*) is added, the pH will decrease only slightly because the H^+ ions will react with $C_2H_3O_2^-$ ions.
c) If NaOH(*aq*) is added, the pH will increase only slightly because the OH^- ions will react with $C_2H_3O_2^-$ molecules.
d) If NaOH(*aq*) is added, the pH will decrease only slightly because the OH^- ions will react with $HC_2H_3O_2$ molecules.

30) The value of the equilibrium constant for water, K_w, at 40°C is 3.0×10^{-14}. What is the pH of pure water at 40°C?

a) 3.0
b) 6.8
c) 7.0
d) 7.2

31) Which of the following best helps to explain why Na(*s*) is more reactive with water than Mg(*s*) is?

a) Na(*s*) is softer than Mg(*s*).
b) The atomic mass of Na is less than that of Mg.
c) The Na^+ ion has weaker Coulombic attraction to an anion than the Mg^{2+} ion has.
d) The first ionization energy of Na is less than that of Mg.

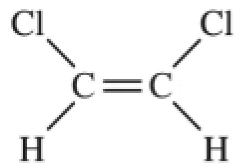
32) Samples of NaF(*s*) and NH_4Cl(*s*) are dissolved in separate beakers that each contain 100 mL of water. One of the salts produces a slightly acidic solution. Which of the following equations best represents the formation of the slightly acidic solution?

a) $Na^+(aq) + 2H_2O(l) \rightleftharpoons NaOH(aq) + H_3O^+(aq)$
b) $F^-(aq) + H_2O(l) \rightleftharpoons HF(aq) + OH^-(aq)$
c) $NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$
d) $Cl^-(aq) + H_2O(l) \rightleftharpoons HCl(aq) + OH^-(aq)$

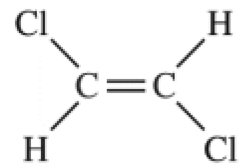
33) $$C(diamond) \rightarrow C(graphite); \quad \Delta G^\circ = -2.9 \text{ kJ/mol}_{rxn}$$

Which of the following best explains why the reaction represented above is not observed to occur at room temperature?

a) The rate of the reaction is extremely slow because of the relatively small value of ΔG° for the reaction.
b) The entropy of the system decreases because the carbon atoms in graphite are less ordered than those in diamond.
c) The reaction has an extremely large activation energy due to strong three-dimensional bonding among carbon atoms in diamond.
d) The reaction does not occur because it is not thermodynamically favorable.



cis-isomer



trans-isomer

34)

The structural formulas for two isomers of 1,2-dichloroethene are shown above. Which of the two liquids has the higher equilibrium vapor pressure at 20°C, and why?

a) The *cis*-isomer, because it has dipole-dipole interactions, whereas the *trans*-isomer has only London dispersion forces.
b) The *cis*-isomer, because it has only London dispersion forces, whereas the *trans*-isomer also has dipole-dipole interactions.
c) The *trans*-isomer, because it has dipole-dipole interactions, whereas the *cis*-isomer has only London dispersion forces.
d) The *trans*-isomer, because it has only London dispersion forces, whereas the *cis*-isomer also has dipole-dipole interactions.

35) The formation of $Fe(s)$ and $O_2(g)$ from $FeO(s)$ is not thermodynamically favorable at room temperature. To make the process favorable, $C(s)$ is added to the $FeO(s)$ at elevated temperatures.

$$CO_2(g) \rightleftharpoons C(s) + O_2(g);\ K_{eq} = 1 \times 10^{-32} \text{ at } 1000\text{ K}$$
$$2FeO(s) \rightleftharpoons 2Fe(s) + O_2(g);\ K_{eq} = 1 \times 10^{-6} \text{ at } 1000\text{ K}$$

Based on the information above, which of the following gives the value of K_{eq} and the sign of $G°$ for the reaction represented by the equation below at 1000 K?

$$2FeO(s) + C(s) \rightleftharpoons 2Fe(s) + CO_2(g)$$

a) $K_{eq} = 1 \times 10^{-38}$, $\Delta G°$ is positive
b) $K_{eq} = 1 \times 10^{-38}$, $\Delta G°$ is negative
c) $K_{eq} = 1 \times 10^{26}$, $\Delta G°$ is positive
d) $K_{eq} = 1 \times 10^{26}$, $\Delta G°$ is negative

Questions 36 & 37 refer to a galvanic cell constructed using two half-cells and based on the two half-reactions represented below.

$$Zn^{2+}(aq) + 2\ e^- \rightarrow Zn(s) \quad E° = -0.76\ V$$
$$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq) \quad E° = 0.77\ V$$

36) As the cell operates, ionic species found in the half-cell containing the cathode include which of the following?

I. $Zn^{2+}(aq)$
II. $Fe^{2+}(aq)$
III. $Fe^{3+}(aq)$

a) I only
b) II only
c) III only
d) I and III
e) II and III

37) What is the standard cell potential for the galvanic cell?

a) -0.01 V
b) 0.01 V
c) 0.78 V
d) 1.53 V
e) 2.31 V

38) A biochemistry student would like to make a solution of 0.1M phosphate buffered saline (PBS) having a pH 7.4. Determine the amount of NaH_2PO_4 and Na_2HPO_4 that must be dissolved in 100 mL to give a pH of 7.4. The dissociation constants are given in the table below:

Acid	Conjugate base	pK_a
H_3PO_4	$H_2PO_4^-$	2.16
$H_2PO_4^-$	HPO_4^{2-}	7.21
HPO_4^{2-}	PO_4^{3-}	12.32

a) 0.25 g NaH_2PO_4, 1.12 g Na_2HPO_4
b) 0.36 g NaH_2PO_4, 0.99 g Na_2HPO_4
c) 0.47 g NaH_2PO_4, 0.87 g Na_2HPO_4
d) 0.76 g NaH_2PO_4, 0.52 g Na_2HPO_4

39) If a metal X forms an ionic chloride with the formula XCl_3, then which of the following formulas is most likely to be that of a stable sulfide of X?

a) XS_2
b) X_2S_3
c) XS_6
d) $X(SO_3)_3$
e) $X_2(SO_3)_3$

40) By mixing only 0.15 M HCl and 0.25 M HCl, it is possible to create all the following solutions EXCEPT

a) 0.23 M HCl
b) 0.21 M HCl
c) 0.18 M HCl
d) 0.16 M HCl
e) 0.14 M HCl

41) At 25°C a saturated solution of a metal hydroxide, $M(OH)_2$, has a pH of 9.0. What is the value of the solubility-product constant, K_{sp}, of $M(OH)_2(s)$ at 25°C?

a) 5.0×10^{-28}
b) 1.0×10^{-27}
c) 5.0×10^{-19}
d) 5.0×10^{-16}
e) 1.0×10^{-15}

42) Heat energy is added slowly to a pure solid covalent compound at its melting point. About half of the solid melts to become a liquid. Which of the following must be true about this process?

a) Covalent bonds are broken as the solid melts.
b) The temperature of the solid/liquid mixture remains the same while heat is being added.
c) The intermolecular forces present among molecules become zero as the solid melts.
d) The volume of the compound increases as the solid melts to become a liquid.
e) The average kinetic energy of the molecules becomes greater as the molecules leave the solid state and enter the liquid state.

Questions 43 & 44 refer to an experiment to determine the value of the heat of fusion of ice. A student used a calorimeter consisting of a polystyrene cup and a thermometer. The cup was weighed, then filled halfway with warm water, then weighed again. The temperature of the water was measured, and some ice cubes from a 0°C ice bath were added to the cup. The mixture was gently stirred as the ice melted, and the lowest temperature reached by the water in the cup was recorded. The cup and its contents were weighed again.

43) The purpose of weighing the cup and its contents again at the end of the experiment was to

a) determine the mass of ice that was added.
b) determine the mass of the thermometer.
c) determine the mass of the water that evaporated.
d) verify the mass of the water that was cooled.
e) verify the mass of the calorimeter cup.

44) Suppose that during the experiment, a significant amount of water from the ice bath adhered to the ice cubes. How does this affect the calculated value for the heat of fusion of ice?

a) The calculated value is too large because less warm water had to be cooled.
b) The calculated value is too large because more cold water had to be heated.
c) The calculated value is too small because less ice was added than the student assumed.
d) The calculated value is too small because the total mass of the calorimeter contents was too large.
e) There is no effect on the calculated value because the water adhered to the ice cubes was at 0°C.

45) Which of the following particles is emitted by an atom of ^{39}Ca when it decays to produce an atom of ^{39}K?

a) $^{4}_{2}He$
b) $^{1}_{0}n$
c) $^{1}_{1}H$
d) β^{-}
e) β^{+}